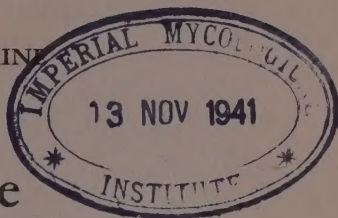


UNIVERSITY OF MAINE



The Maine
Agricultural Experiment
Station

ORONO

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Results of Testing Some Laboratory
Methods for Possible Use in the
Detection of Virus Diseases
in Potato Tubers

/D. FOLSOM/

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RESULTS OF TESTING SOME LABORATORY
METHODS FOR POSSIBLE USE IN THE
DETECTION OF VIRUS DISEASES
IN POTATO TUBERS

BY DONALD FOLSOM

INTRODUCTION

The potato (*Solanum tuberosum* L.) is known to be susceptible to about two dozen distinct virus diseases (7).¹ The economic importance of potato virus diseases differs much with the variety of the host, the region, and other factors, but altogether is great enough to stimulate considerable effort toward their control. The most promising general methods of control seem at present to be (1) the selection and production of resistant varieties, (2) the selection, within a susceptible variety, of the less infected seed stocks, and (3) the selection, within a seed stock, of healthy tubers. The most reliable method of seed-stock selection available has required the examination of the plants in the summer in the field, which of course is unsatisfactory to those who wish to select seed in other seasons. The most dependable method of seed-tuber selection has necessitated planting sample eyes in the greenhouse or in a southern region and growing the resulting plants there, which is expensive. For these reasons it has been obvious that there would be advantages from practical and reliable methods of testing the tubers for virus diseases. Such methods would not only permit the selection of healthy seed tubers and seed stocks, but would permit quicker and easier determination of susceptibility in new seedling varieties, especially of the carrier type.

In describing the general results of various tests for virus diseases in potato tubers, it is desirable to indicate the method, diseases, host varieties, regions, whether the disease was chronic or recently contracted, whether the difference was applicable to individual tubers or only average, and whether or not the method was practical.

¹ Italic numbers in parentheses refer to Literature Cited, p. 103.

A method might not be practical unless it permitted the testing of several hundred tubers a day by a technician and an assistant. This is because of the number of tubers required in a sample if its percentage of diseased plants is to be reliably representative of the whole seed stock. For example, according to Hartzell [11, p. 208, formulas (11) and (12)] and Youden (21, p. 227, formula 2). with 2 per cent disease in 2,500 tubers the P.E. = ± 0.19 per cent and with 3 per cent disease the P.E. = ± 0.23 per cent. The difference of 1.0 per cent has a probable error of ± 0.30 per cent according to the formula, P.E. of difference is the square root of the sum of the squares of the two probable errors. The ratio of 1.0/0.30 gives about the minimum odds for significance. Assuming that about 2 or 3 per cent disease is as much as growers can afford to rogue from seed stocks, they would have to secure readings on about 2,500 representative tubers per seed stock to be sure of a difference of 1 per cent at the critical incidence of disease.

The "Abbau" of many German writers may sometimes be concerned with virus diseases only partly, or even not at all, without disclosure of the fact in the account. This is realized by Es-march (6, p. 75). His monograph on leafroll (6) includes a review of work showing some differences in the tuber caused by this disease but they have no practical bearing on control (6, p. 80).

With respect to mild mosaic, rugose mosaic, spindle tuber, and leafroll, lack of practical results was reported (17, pp. 213-215) from a number of simple tests made by the author. These were concerned with:

- Bacterial rot of tubers
- Catalase
- Discoloration of pulp
- Cutin and suberin
- Flesh hardness
- Formaldehyde traces in tissues
- Hydrogen-ion concentration of the extract
- Iron (no rugose mosaic tested)
- Lignin
- Pentosans
- Nitrates
- Nitrites
- Oxidases (no mild mosaic tested)
- Pectin (no spindle tuber tested)

Peroxidase (mild and rugose mosaic only tested)
Potassium (leaf roll and rugose mosaic only tested)
Protein
Skin toughness
Specific gravity
Sprout brittleness, form, number, and size
Tannin (leafroll and rugose mosaic only tested)
Tuber form and size
Tyrosine and tyrosinase

Many other persons have published on this problem but a review is not possible here. It may suffice to say that there is yet no practical chemical or physical tuber test available, and that seed certification and the winter growing of samples in greenhouses or southern regions are the best methods in use for judging the amount of virus diseases present in seed stocks.

In the experiments newly described here, methods evidently too slow to be practical, as defined above, were largely ignored, although it was recognized that it might be possible for a slow effective method to be improved as to rapidity. The variety of potato was the Green Mountain and the tested tubers had been produced in Maine. The technique of the tests is described briefly in the chronological order of their first trials, and the results are given later in corresponding sequence.

A method may disclose average differences, between diseased and healthy seed stocks or tubers, that are not confirmed by all the individual tubers. That is, the ranges of results of measurements of two series of tubers may overlap each other even though the difference between the means is significant. A test method, to be effective, should distinguish all diseased tubers from all healthy tubers.

Also, a method may be either more (or less) valuable for distinguishing between chronically diseased stocks than for isolating recently infected tubers. For example, spindle-tuber shape of tubers, where present, may serve to identify chronic infection² but is seldom shown by the tubers of recently infected plants. Again, on the other hand, net necrosis is absent in stocks that have been leafroll for over a year but may serve to isolate some tubers which recently contracted leafroll.

² "Chronic infection" here means infection entering the parent plants through the seed pieces.

Tests of methods to isolate recently infected tubers require the use of part of each tuber, at least at the extremes of the measurements obtained, for growing plants. These plants must be grown under conditions known to be suitable for bringing out the symptoms. It is necessary also, if waste of time is to be avoided, to test such methods only on stocks grown under conditions inducing infection.

EXPERIMENTAL TECHNIQUE³

Tuber cracking. Tubers of uniform weight were released at a height of 2 feet 3 inches (about 0.7 m.) onto a wooden floor.

Skin toughness. By means of an instrument in commercial use for the testing of the maturity of kernels of corn (*Zea Mays* L.), a stiff wire with a cross-section area of 0.00554 sq. cm. or 0.00086 sq. in. was forced into the tuber in a position vertical to the surface. The initial resistance of the skin compressed a spiral wire spring and moved a marker along a graduated scale. When the skin broke, which occurred at a pressure of about 45 kg. per sq. m. or about 625 lbs. per sq. in., the compression of the spring was released and the position of the marker, left at the point of maximum compression, was read as the index of skin toughness.

Periderm thickness. Free-hand sections were examined microscopically as to the thickness of the periderm.

Specific gravity. Water displacement was used to determine the volume of the weighed tuber, and the specific gravity was then calculated.

Flesh hardness. Pressure testers suitable for use in pome and drupe fruits, whose flesh yields gradually, are not all adaptable to the potato tuber, whose flesh is harder and collapses rather suddenly under pressure. Thus it was found that the California pistol-grip type (1, Fig. 4) was useless with potatoes. The Magness and Taylor type (12; 1, Fig. 3) was used in 1926-27⁴ and the Blake peach tester (3), with the 3/16-inch (5 mm.) plunger, was used in 1930-31.

³ See the next section of this bulletin, beginning on p. 90, for experimental results from the technique described here.

⁴ Referring to the winter season, tests being made on the crop grown in 1926.

Weight and loss of weight. In 1928-29, tubers from cold-cellar storage were washed, dried, weighed, exposed continually to rather stagnant indoor air with a temperature of 80° to 84° F. (about 28° C.) and a relative humidity of 25 to 30 per cent, and weighed at regular intervals for 28 days.

In 1929-30, tubers, as soon as dug, were shipped by freight to the laboratory, where they were washed, dried, and weighed at regular intervals for 130 days while exposed continually to rather stagnant indoor air with a temperature of 70° to 75° F. (21° to 24° C.) and a relative humidity of 25 to 30 per cent.

Freezing injury. In 1928-29, tubers were kept for four months in cellar storage of 35° to 45° F. (about 2° to 7° C.) and then a part of each tuber was exposed to low temperature in small refrigerating chambers. The low temperature, time of exposure to it, and amount of tuber tissue in the chamber, were controlled so as to induce the final "leaker" stage in only a few tubers. This meant, in the available cabinets, an initial or normal temperature of about 20° F. (6.6° C.), the introduction of about 2,100 grams of material, and its removal in about nine hours. After the tubers were warmed and allowed to stand for a few days, an examination was made for the well-known types of freezing injury. (See 20.)

Refractive index. Tubers and parts of tubers were frozen solid in the small refrigerating cabinets or in the open, at temperatures near 0° F. (-18° C.) during the night. In the morning each frozen tuber or tuber part was exposed to room temperature in a separate dish for several hours. By this time the leaker stage of freezing injury had been reached by the tuber, from which juice was squeezed easily by hand. This juice was stirred and a drop examined for its refractive index in an Abbe refractometer. According to Sherwood (18, p. 51), a few drops of juice, pressed out of pulp with the fingers, are sufficient, with the refractometer, for determining the total soluble solids of individual sugar beets. Likewise Craig (4) found that juice pressed out by hand from sugar cane was satisfactory for determining the sugar content of seedlings by means of a refractometer. According to Dixon and Atkins (5, p. 424), immersion in liquid air gives leaf sap apparently like that in uninjured cells, shown by plasmolysis tests, and different from sap obtained by pressure which gives more concentrated sap with successive use. Gassner and Goeze (9) found that the concentration of sap from killed plant parts was not affected by variations in

pressure or comminution of material and was about the same as that of sap from living parts. Gortner and Hoffman (10, pp. 312-313) believe that "the refractometer reading more nearly expresses the true value of the moisture content than can be obtained by any known method." They refer to plant tissue fluids expressed after freezing.

With reference to a basic refractive index of 1.3400, the juice from the frozen tubers gave a somewhat (about 0.0010) higher reading after the warming period than at its beginning. This may possibly be explained in part by the facts that juice from the center of the tuber gave a similarly higher reading than from the cortex, and that the center was the last to thaw out. The ends of the tuber were alike. More squeezing of juice from the same tuber, after complete thawing, increased the reading about 0.0010 within a few hours. However, tuber variation ran through a range of about 0.0045, and sometimes the individual readings of samples from the same tuber varied as much as 0.0010. The instrument is of a type not claimed by the manufacturer (Zeiss) to have an accuracy of more than about 0.0002.

Resistance to alternating electric current. Two blunt-pointed pieces of platinum wire 1.50 mm. in diameter were fixed about 11 mm. apart, projecting about 18 mm. from hollow glass holders containing mercury in contact with the platinum. Alternating 60-cycle electric current of about 110 volts from a commercial supply was passed through a circuit including the platinum electrodes immediately after they had been inserted into tuber tissue. The conductivity was measured with a voltmeter in the series. As a check for each tuber, a copper-alloy wire screen was used bridging the points; the potential difference varied with the load in the building, from 101 to 113 volts.

In 1928-29, each tuber was read in three places—at both ends and midway between. In 1929-30, four readings were taken in each tuber, one at each end and two midway. In 1930-31, five readings were taken in each tuber, one at each end, one midway between the ends in each face (upper and lower), and one midway between the ends in an edge, that is, midway also between the two pairs of facial punctures. ("Upper" and "lower" faces, while meaning the "dorsal" and "ventral" sides, respectively, also happen to designate the natural position in the soil; the upper or dor-

sal face is more convex and has more eyes. See 8, p. 6.)

Color in fat frying. Slices from tubers were cooked as potato chips in hot fat in the course of experiments made by Marion D. Sweetman,⁵ who has shown that darker color of chips indicates more sugar in them, which in turn is one result of colder storage (19).

Flavone, oxidase, and tyrosinase tests, and steeping in nicotine. These procedures were carried out in 1928-29 as directed by McIntosh (13).

Generation of electric current. Two electrodes of different kinds of metal were forced into the tuber. In 1930-31 and in 1934-35, they were respectively of copper and zinc, about 8 mm. apart, each triangular with base 14 mm. long and height 10 mm., and the current passing between them in the tuber tissues was measured with a small portable galvanometer. Readings were taken from the same parts of the tuber as for the tests on resistance to alternating current.

In 1933-34, the electrodes were like the platinum ones used in the study of resistance to alternating current, in shape and size, but, aside from the platinum ones, were supplied in aluminum, copper, iron, nickel, silver, and tin along with a micro-ammeter in which they were inserted and held for penetration into the tuber. The resulting current was measured by a needle on a scale of 100. The device, called an "electrynx," was kindly loaned by the Westinghouse Electric and Mfg. Co., of New York City.

Hydrogen-ion concentration. In 1930-31, after tubers had been frozen and thawed and the expressed juice sampled for a reading of the refractive index, the juice was corked up in small vials and its pH determined electrometrically within a few hours.

Copper-contact discoloration. In 1933-34, following the directions of students of "Abbau" (2, p. 133-134), copper bands were inserted into tubers which were then exposed to conditions of high temperature (37° C.) and high humidity. After reduction of the temperature to 20° C., further exposure to high humidity, and an examination of the tissues next to the wound made by the copper band, comparisons were made as to discoloration.

⁵ Professor of Home Economics in the College of Agriculture and Collaborating Home Economist in the Agricultural Experiment Station.

Water intake. Following the suggestion by students of "Abbau" (2), tubers were weighed, cut in two across, immersed in water, and weighed in about 50 hours to determine the water intake.

EXPERIMENTAL RESULTS

The results of employing the different kinds of technique that have been described, arranged in corresponding sequence, sometimes include data, on the physiology of the potato tuber, that do not bear solely on the question of the effects of virus diseases.

Tuber cracking. Tuber cracking caused by dropping, as described on p. 86, occurred in all chronic spindle-tuber tubers in 1925 but in less than half of the healthy tubers.

Skin toughness. The pressure required to break the skin in 1925-26⁶ was not changed by chronic giant-hill but was reduced slightly on the average by chronic spindle tuber. More pressure was required, in the same tuber, with progress from stem (proximal) end to bud (distal) end.

Contrary to the results with chronic spindle tuber, recent infection by spindle tuber was greater in classes of tubers which required higher pressure for skin breakage. Mild mosaic of recent infection showed a tendency in the same direction. However, in neither case did the test differentiate individual tubers.

In 1926-27, chronic spindle tuber again reduced skin toughness. Its close relative, unmottled curly dwarf, reduced it still more. Slight reduction was shown by leafrolling mosaic, rugose mosaic, crinkle mosaic, Aucuba mosaic, interveinal mosaic, and leafroll, but none by mild mosaic and giant-hill. However, because the range of skin toughness by individual tubers in each stock was so great, there was much overlapping by the ranges of the stocks with different diseases. The five punctures in one tuber often varied as much as the averages for the tubers in one stock. An attempt to disclose possible correlation between tuber size and skin toughness in one lot failed.

⁶ Referring to the winter season, tests being made on the crop grown in 1925.

Periderm thickness. Periderm thickness in 1925-26 was not affected by chronic giant-hill or spindle tuber and was not correlated with skin toughness as determined with the corn-maturity tester.

Specific gravity. Chronic giant-hill and spindle tuber in 1925-26 did not influence specific gravity, which varied greatly with individual tubers.

Flesh hardness. In 1926-27, chronic spindle tuber and unmottled curly dwarf reduced flesh hardness more than did chronic leafrolling mosaic, rugose mosaic, crinkle mosaic, Aucuba mosaic, interveinal mosaic, and leafroll, while mild mosaic and giant-hill gave a slight increase. However, the range shown by individual tubers in each stock was too great to permit the separation of any stock from the others by this method. Flesh hardness just below the skin, where usually sampled, was slightly less than in the center of the tuber. The five punctures in one tuber often varied as much as the averages for the tubers in one stock. No correlation was found between tuber weight and flesh hardness.

In 1930-31, in stock kept in a warm room, the peach-tester index was decreased by chronic spindle tuber from 6.9-8.3 to 5.7-6.7 in decade averages and was increased by leafroll from 7.0 to 7.9, but was not changed by mild mosaic, rugose mosaic, or giant-hill. In recently and partly infected stock, rugose mosaic tubers were found to be mixed with healthy in both high- and low-reading classes. The index did not vary with tuber weight in a comparison of 260 tubers in 5 stocks; it decreased with change of location from stem end to edge midway, faces midway, or bud end of the tuber; and it was not affected much by removal of the skin, but was reduced somewhat by the removal of a thick slab of cortex. The index was higher in tubers from southwestern Maine than in tubers from northeastern Maine.

In 1930-31, in stock kept in cold storage at 32° to 40° F. (0° to 4° C.) for five months and then for a month in a warm room, the peach-tester index was again decreased by chronic spindle tuber, from 7.0 to 5.7, decreased still more by rugose mosaic, and unchanged by mild mosaic and leafroll. In recently and partly infected stock, mild mosaic and rugose mosaic tubers were found mixed with healthy in both high- and low-reading classes, and leafroll was present in both high- and low-reading tubers,

the leafroll tubers being mixed with healthy in the low-reading class. The index did not vary with tuber weight in a comparison of 260 tubers in 7 stocks.

Weight and loss of weight. In 1928-29, losses in 28 days in a warm, dry room were about 0.20 per cent of the original tuber weight per day. With less original weight of tuber, the loss was less absolutely but greater in percentage. Lesions, or cuts, present in a few tubers, increased the loss slightly, to 0.21 per cent per day. Chronic mild mosaic, rugose mosaic, spindle tuber, and giant-hill did not change the rate of loss. Chronic leafroll decreased the rate of loss in most tubers by various amounts up to a third. Tubers from healthy stock, exposed to leafroll infection during the previous growing season, showed similar decrease in some tubers and as much increase in others. This variation from the norm was more common with less tuber weight. Upon being planted, the exposed healthy stock produced leafroll plants from 31 per cent of the tubers losing most weight, from 37 per cent of those losing least, and from 27 per cent of the remainder. The test obviously failed to differentiate recently infected tubers, which is contrary to results reported by McLean (14), and not even these average differences can be considered as being caused by a relationship between weight loss and recent leafroll infection. Such infection was correlated, however, with greater tuber weight, as reported previously (16, p. 71), inasmuch as the leafroll percentage was 23, 31, and 56, respectively, for the weight classes of tubers of up to 100 grams, 101 to 200 grams, and 201 to 300 grams (the maximum).

In 1929-30, losses in a warm, dry room were about 10.8 per cent of the original weight in 130 days, or about 0.08 per cent per day. The largest tubers, with the most advanced sprouts at the end of the test period, and the smallest tubers, with the most surface per unit of volume, lost slightly more, 0.09 per cent per day. Lesions or cuts had no effect on loss. Growing plants in the greenhouse showed that leafroll from recent infection was present in some of the tubers with the most loss and was present in like amount in those with the least loss.

Freezing injury. Tubers grown in a healthy field in central Maine, after exposure to artificial freezing, all showed injury in the class above 200 grams while 33 per cent were apparently un-

injured at 110 to 200 grams and 41 per cent at 100 or less grams. On the other hand, the most severe (leaker) type of injury was present in 7, 23, and 30 per cent respectively of the same weight classes. Therefore the larger the tuber, the more chance it had of showing some injury other than the leaker type, such as net, ring, or blotch discoloration. However, tubers grown in another part of the same field gave different results, the 300-gram weight being at or near the maximum for each kind of injury, as expressed in percentage of tubers affected. Storage temperature during the day just previous to freezing had no effect, or only a slight one, upon the amount of injury. Chronic mild mosaic, rugose mosaic, and spindle tuber had no effect, giant-hill increased discoloration injury, and three other varieties differed from the Green Mountains, but the indistinctness of the differences and the tuber variation in each stock made differentiation of disease or variety impossible by the freezing-injury method.

Refractive index. In 1928-29, the refractive index of the juice squeezed from the frozen and thawed leaker tubers showed, in the same stock, no correlation with the original tuber weight. The index ranged from 1.3416 to 1.3461 and the weight ranged from 30 to 665 grams with a small and nonsignificant correlation coefficient ($r = -0.043 \pm 0.052$ for 171 tubers).

Samples from the same stock stored at 35° to 40° F. (about 3° C.) in several weeks gave an increase from 1.3405 to a final reading of over 1.3470. Stored in a barrel standing on the cold floor, a sample showed 1.3460 while similar stock in a barrel standing on the first barrel showed only 1.3440. These differences probably owe their explanation to the well-known fact that potato tubers show an increase in sugar with lower temperature, or with longer storage at low temperature.

No correlation was apparent between the refractive index of juice from one part of a tuber and type of freezing injury induced in another part of the same tuber.

With due regard for the known causes of differences in the refractive index, no distinction could be made between five varieties, which gave similar means and overlapping ranges. Chronic spindle tuber caused a considerable lowering and leafroll a slight increase, in comparison with mild mosaic, rugose mosaic, giant-hill, and healthy stocks. What recent infection would do was test-

ed in stocks healthy when planted but exposed to disease during the previous growing season. In the case of mild mosaic, rugose mosaic, and leafroll, the high-refraction tubers included both diseased and healthy, and so did the low-refraction tubers. Spindle tuber had not spread and so the test on this disease was abortive.

In 1929-30, the index ranged from 1.3403 to 1.3422, as averages of ten-tuber samples, with about the same results for chronic mild mosaic, leafroll, spindle tuber, and healthy. The index was not affected by tuber weight, by sampling a stock on successive dates, or by rate of freezing. The index was the same for the two ends of the tuber cut apart before freezing. It varied somewhat with time of digging and place of storage, in the same stock, and with the variety. Length of small sprouts (2 vs. 6 mm.) did not affect the index.

In stocks with recent infection, mild mosaic and rugose mosaic tubers were mixed with healthy in both low- and high-reading classes.

In 1930-31, in stock kept in a warm room, the index varied from 1.3398 to 1.3420, as averages from ten-tuber samples, with about the same results for healthy, chronic mild mosaic, leafroll, spindle-tuber, and giant-hill stocks, but with an increase of 0.0005 to 0.0010 for chronic rugose mosaic. The index was not affected by tuber weight in a comparison of 420 tubers in 5 stocks. In stocks with recent infection, mild mosaic and rugose mosaic tubers were mixed with healthy in high-reading classes. In 14 decade-averages of tubers from 3 stocks, a comparison of refractive index and flesh-hardness index disclosed a highly significant negative correlation ($r = -0.878 \pm 0.041$).

In 1930-31, in stock kept in cold storage at 32° to 40° F. (0° to 4° C.) for five months and then for a month in a warm room, the index varied from 1.3408 to 1.3425, as averages of ten-tuber samples, with an increase of 0.0011 to 0.0017 for chronic mild mosaic, rugose mosaic, leafroll, and spindle tuber. The index was not affected by tuber weight in a comparison of 440 tubers in 5 stocks. In stocks with recent infection, mild mosaic and leafroll tubers were mixed with healthy in both high- and low-reading classes, and rugose mosaic was present in both high- and low-reading tubers while absent from others.

In 1934-35, in stock kept in a warm room, the index varied

from 1.3419 to 1.3424, as averages of ten-tuber samples from chronic mild mosaic, rugose mosaic, leafroll, spindle-tuber, and healthy stocks. The index varied much more than that, with individual tubers in each ten-tuber sample, and so could not be used to detect disease.

Resistance to alternating electric current. In 1928-29, after tubers had been frozen solid and thawed, they reduced the reading of the voltmeter only slightly (5 to 7 volts). Generally there was less reduction in the reading with more severe freezing injury if the leaker stage had been reached, but occasionally the reading was reduced 45 with leaker symptoms present while being reduced only 38 with no leaker symptoms apparent. Neither frozen tubers nor those taken directly from storage showed differences in conductivity associated with chronic mild mosaic, rugose mosaic, leafroll, spindle tuber, or giant-hill. Unfrozen tubers reduced the reading by 53 to 56 volts.

No correlation was apparent between the resistance to alternating current in one part of the tuber and either the type of freezing injury induced, or the refractive index after freezing, in the other part of the same tuber.

In 1929-30, tubers taken from storage showed more resistance to the passage of the alternating current with smaller weight of tuber, so that tuber weight was kept similar in other comparisons. There was less resistance with chronic leafroll and spindle tuber present than with no disease or with chronic mild mosaic, rugose mosaic, or giant-hill present. This held for all of 25 comparisons, with average differences of 3 to 9 volts per comparison. There was progressively less resistance with change in location of the electrodes from stem end to edge midway to face midway to bud end. It made no difference, in the index, whether or not one electrode pierced an eye, or whether or not the plane containing the two inserted wires cut the tuber across or lengthwise. In the same stock, resistance did not change on successive dates in fresh samples of tubers, but it showed some variation in the same tubers on successive dates after the mutilation of the tubers due to the readings. There was some variation in the same stock corresponding to differences in location of storage of parts of the stock. Several varieties differed from each other, with less resistance (greater conductivity) as the refractive index was greater. With

longer sprouts (6 vs. 2 mm.) there was a slight but significant decrease in the index.

It next was in order to test for recent spindle-tuber infection, but unfortunately the preceding growing season had been abnormal in that no spread of this disease had occurred in the stock used for the test. Tubers recently infected with mild mosaic and rugose mosaic were mixed with healthy in both high- and low-reading classes.

In 1930-31, in stock kept in a warm room, the electrical resistance was not affected by tuber weight in a comparison of 400 tubers in 4 stocks, but was again less with chronic leafroll and spindle tuber present than with no disease or with chronic mild mosaic, rugose mosaic, or giant-hill present. Again there was progressively less resistance with change in location of the electrodes from stem end to edge midway to face midway to bud end. In stocks with recent infection, mild mosaic tubers were mixed with healthy in low-reading classes and rugose mosaic tubers were mixed with healthy in both high- and low-reading classes. Regional source of stock had no effect. No correlation was apparent between resistance and flesh hardness in 250 tubers, mostly healthy, or between resistance and refraction index in 350 tubers, mostly healthy.

In 1930-31, in stock kept in cold storage at 32° to 40° F. (0° to 4° C.) for five months and then for a month in a warm room, the resistance was not affected by tuber weight in a comparison of 370 tubers in 5 stocks, but it was less with chronic rugose mosaic, leafroll, and spindle tuber, than with chronic mild mosaic or in healthy stock. In stocks with recent infection, mild mosaic and leafroll tubers were mixed with healthy in both high- and low-reading classes, and rugose mosaic was present in both high- and low-reading tubers and absent from those intermediate. Regional source of stock had no effect.

In 1934-35, in stock kept in a warm room, the resistance once more was reduced in chronic leafroll and spindle-tuber stocks in comparison with mild mosaic, rugose mosaic, and healthy. Resistance was not correlated with tuber weight.

Color in fat frying. In 1928-29, tubers were chosen from a stock that had been healthy and exposed to leafroll infection the previous growing season—seven for giving slices that were darker

than the average when made into potato chips, and seven for lighter color. Only one, or 7 per cent, of the 14 tubers produced leafroll plants, while 29 per cent of 276 other tubers of this stock produced leafroll plants. Therefore there was no apparent correlation between recent leafroll infection and color of potato chips.

Flavone, oxidase, and tyrosinase tests, and steeping in nicotine. Although recommended for detecting varietal differences in Scotland, these procedures did not differentiate between several American varieties or between chronic mild mosaic, rugose mosaic, leafroll, and spindle tuber.

Generation of electric current. In 1930-31, in stock kept in a warm room, the current generated by piercing a tuber with a copper-and-zinc pair of electrodes was not changed much by chronic mild mosaic, rugose mosaic, leafroll, spindle tuber, or giant-hill. The current was somewhat less with less tuber weight, in some stocks, especially those from northeastern Maine. In stock with recent infection, mild mosaic tubers were mixed with healthy in high-reading classes. The generated current showed no correlation with flesh hardness or the refraction index, but was very significantly greater as resistance to alternating current was less ($r = -0.666 \pm 0.059$ for the 45 decade-averages).

In 1930-31, in stock kept in cold storage at 32° to 40° F. (0° to 4° C.) for five months and then for a month in a warm room, the amount of current generated was not changed by chronic rugose mosaic but was increased slightly by chronic mild mosaic, leafroll, and spindle tuber. Again the current was somewhat less with less tuber weight, in stocks from northeastern Maine. In stocks with recent infection, mild mosaic and rugose mosaic tubers were mixed with healthy in both high- and low-reading classes. The generated current was apparently not correlated with resistance to alternating current.

In 1933-34, the current, set up by combinations of several metals, as measured by the micro-ammeter, gave differences of 13 to 20 units in successive measurements even in the same sample of drinking water, used as a check test. The readings varied still more with successive measurements in the same tuber, using a combination (tin at + and iron at —) that gave a reading within the limits of the scale on the micro-ammeter.

In 1934-35, with the original device, in stock kept in a warm

room, the current again was increased slightly by chronic mild mosaic, leafroll, and spindle tuber, but was not changed by chronic rugose mosaic. The current was not correlated with resistance to alternating current in the same tubers.

Hydrogen-ion concentration. In 1930-31, in stock kept in a warm room, the pH of the juice of frozen tubers was not changed by chronic mild mosaic, rugose mosaic, leafroll, spindle tuber, or giant-hill more than 0.14 in comparable decades. Location of source had greater effect, pH being higher in stock from northeastern (6.26-6.40) than from southwestern Maine (6.06-6.34). In some stocks the pH tended to be higher with less tuber weight, among the low-weight classes. In recently infected stocks, rugose mosaic tubers were mixed with healthy in both high- and low-reading classes. No correlation was apparent between pH and flesh hardness, refractive index, resistance to alternating current, or generation of current.

In 1930-31, in stock kept in cold storage at 32° to 40° F. (0° to 4° C.) for five months and then for a month in a warm room, the pH again did not differ much with chronic disease, was higher in stock from northeastern Maine, and in some stocks tended to be higher with less tuber weight, in the smaller tubers. With the pH ranging per tuber from 6.15 to 6.50 in recently infected stocks, mild mosaic and leafroll tubers were mixed with healthy in both high- and low-reading classes, while rugose mosaic tubers were in both high- and low-reading classes and were mixed with healthy in the high-reading class. The pH was not apparently correlated with refractive index in the same tuber.

Copper-contact discoloration. In 1933-34, the copper-band method was found not to differentiate between chronic mild mosaic and healthy tubers.

In 1934-35, the method did not differentiate between chronic mild mosaic, rugose mosaic, leafroll, spindle tuber, and healthy tubers.

Water intake. In 1934-35, in stock kept in a warm room, small sprouts up to 6 mm. in length were removed, the tubers were cut, and the percentage of increase in weight from immersion in water was ascertained. This varied too much according to the weight ($r = -0.675$ for 20 tubers) to permit its use in distinguishing chronic mild mosaic, leafroll, or spindle tuber.

Miscellaneous tests. In 1934-35, chronic mild mosaic, leaf-roll, and spindle-tuber tubers were not differentiated from each other or from healthy tubers by immersion in toluol-treated water, by colorimetric pH indicators, or by attempting to stain in mass or on a spot plate with phenosafranin. Failure also met the use of the pH indicators with chronic rugose mosaic tubers and the use of the phenosafranin with several varieties. (For successful results with the latter on varieties see 15, p. 268.)

In 1935-36, chronic mild mosaic, rugose mosaic, leafroll, spindle-tuber, and healthy tubers were not differentiated consistently from each other by the microscopic appearance of their starch mounted in their own juice, though translucency and striations seemed to be generally less marked with spindle tuber.

DISCUSSION AND CONCLUSIONS

Effectiveness of tests for viroses. The experimental tests newly reported in this paper are summarized in Table 1. About 50 gave an average difference, in respect to the measured characteristic, correlated with chronic disease. About 90 gave no average difference with chronic disease. Recent infection was correlated with an average difference in 3 instances, while in about 35 there was no consistent tuber difference associated with recent infection. Average differences are much more common with leaf-roll and spindle tuber than with mild mosaic or rugose mosaic. It seems desirable, as soon as locations are known wherein leafroll is naturally disseminated to a sufficient degree, to repeat some of these tests with a view to detecting recent infection by leafroll.

TABLE 1

Experimental results of testing potato tubers for virus diseases

Kind of test ¹	Year of test	Disease	Infection	Difference tested	Correlation
Tuber cracking	1925	Spindle tuber	Chronic	Average ²	Positive
	1925-26	Spindle tuber	Chronic	Average ²	Negative
			Recent	Average ²	Positive
		Giant hill	Chronic	Average	None
		Mild mosaic	Recent	Average ²	Positive
Skin toughness	1926-27	Leafroll	Chronic	Average ²	Negative
		Spindle tuber	Chronic	Average ²	Negative
		Unmottled curly dwarf	Chronic	Average ²	Negative
		Giant hill	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
		Rugose mosaic	Chronic	Average ²	Negative
		Crinkle mosaic	Chronic	Average ²	Negative
		Leafrolling mosaic	Chronic	Average ²	Negative
		Intervenal mosaic	Chronic	Average ²	Negative
		Aucuba mosaic	Chronic	Average ²	Negative
Periderm thickness	1925-26	Spindle tuber	Chronic	Average	None
		Giant hill	Chronic	Average	None
Specific gravity	1925-26	Spindle tuber	Chronic	Average	None
		Giant hill	Chronic	Average	None
Flesh hardness	1926-27	Leafroll	Chronic	Average ²	Negative
		Spindle tuber	Chronic	Average ²	Negative
		Unmottled curly dwarf	Chronic	Average ²	Negative
		Giant hill	Chronic	Average ²	Positive
		Mild mosaic	Chronic	Average ²	Positive
		Rugose mosaic	Chronic	Average ²	Negative
		Crinkle mosaic	Chronic	Average ²	Negative
		Leafrolling mosaic	Chronic	Average ²	Negative
		Intervenal mosaic	Chronic	Average ²	Negative
		Aucuba mosaic	Chronic	Average ²	Negative
	1930-31	Leafroll	Chronic	Average ²	Positive
		Spindle tuber	Chronic	Average ²	Negative
		Giant hill	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
	1930-31 ³	Rugose mosaic	Chronic	Average	None
		Leafroll	Recent	Individual	None
			Chronic	Average	None
			Recent	Individual	None
		Spindle tuber	Chronic	Average ²	Negative
		Mild mosaic	Chronic	Average	None
			Recent	Individual	None
		Rugose mosaic	Chronic	Average ²	Negative
Weight	1928-29	Leafroll	Recent	Average ²	Positive
	1928-29	Leafroll	Chronic	Average ²	Negative
Loss of weight		Spindle tuber	Recent	Average	None
		Giant hill	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
		Rugose mosaic	Chronic	Average	None
Freezing injury	1929-30	Leafroll	Recent	Individual	None
	1928-29	Spindle tuber	Chronic	Average	None
		Giant hill	Chronic	Average ²	Positive
		Mild mosaic	Chronic	Average	None
			Recent	Individual	None
		Rugose mosaic	Chronic	Average	None
			Recent	Individual	None
		Leafroll	Chronic	Average ²	Positive
Refractive index	1928-29	Spindle tuber	Recent	Individual	None
		Giant hill	Chronic	Average ²	Negative
		Mild mosaic	Chronic	Average	None
			Recent	Individual	None
		Rugose mosaic	Chronic	Average	None
			Recent	Individual	None
		Leafroll	Chronic	Average ²	None
		Spindle tuber	Chronic	Average	None
	1929-30	Giant hill	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
			Recent	Individual	None

¹ See text for description of method or test and of results.² Individual difference also tested but found to have no correlation with the disease.³ The two tests of 1930-31 were respectively on stocks kept in a warm room and in cold storage.

TABLE 1—(Continued)

Kind of test ¹	Year of test	Disease	Infection	Difference tested	Correlation
Refractive index	1930-31	Rugose mosaic	Recent	Individual	None
		Leafroll	Chronic	Average	None
		Spindle tuber	Chronic	Average	None
		Giant hill	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
	1930-31 ^a	Rugose mosaic	Recent	Individual	None
			Chronic	Average ²	Positive
		Leafroll	Recent	Individual	None
			Chronic	Average ²	Positive
		Spindle tuber	Recent	Individual	None
			Chronic	Average ²	Positive
		Mild mosaic	Recent	Individual	None
			Chronic	Average ²	Positive
		Rugose mosaic	Recent	Individual	None
			Chronic	Average ²	Positive
	1934-35	Leafroll	Chronic	Average	None
		Spindle tuber	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
		Rugose mosaic	Chronic	Average	None
	1928-29	Leafroll	Chronic	Average	None
		Spindle tuber	Chronic	Average	None
		Giant hill	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
	1929-30	Rugose mosaic	Chronic	Average	None
		Leafroll	Chronic	Average ²	Negative
		Spindle tuber	Chronic	Average ²	Negative
		Giant hill	Chronic	Average	None
Resistance to alternating current	1930-31	Mild mosaic	Chronic	Average	None
		Rugose mosaic	Recent	Individual	None
			Chronic	Average	None
		Leafroll	Chronic	Average ²	Negative
		Spindle tuber	Chronic	Average ²	Negative
	1930-31 ^a	Giant hill	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
		Rugose mosaic	Recent	Individual	None
			Chronic	Average	None
		Leafroll	Recent	Individual	None
	1934-35	Spindle tuber	Chronic	Average ²	Negative
		Mild mosaic	Chronic	Average ²	Negative
		Rugose mosaic	Chronic	Average	None
		Leafroll	Chronic	Average	None
		Spindle tuber	Chronic	Average	None
Color in fat frying Flavone etc.	1928-29	Mild mosaic	Chronic	Average	None
		Rugose mosaic	Recent	Individual	None
	1928-29	Leafroll	Chronic	Average	None
		Spindle tuber	Chronic	Average	None
	1930-31	Mild mosaic	Chronic	Average	None
		Rugose mosaic	Chronic	Average	None
	1930-31	Leafroll	Chronic	Average	None
		Spindle tuber	Chronic	Average	None
	1930-31 ^a	Giant hill	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
Electric current generated	1930-31 ^a	Rugose mosaic	Chronic	Average ²	Positive
		Leafroll	Chronic	Average ²	Positive
	1934-35	Spindle tuber	Chronic	Average ²	Positive
		Mild mosaic	Chronic	Average ²	Positive
	1930-31	Rugose mosaic	Recent	Individual	None
			Chronic	Average	None
	1934-35	Leafroll	Recent	Individual	None
		Spindle tuber	Chronic	Average	None

TABLE 1—(Concluded)

Kind of test ¹	Year of test	Disease	Infection	Difference tested	Correlation
pH	1930-31	Leafroll	Chronic	Average	None
		Spindle tuber	Chronic	Average	None
		Giant hill	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
		Rugose mosaic	Chronic	Average	None
	1930-31 ³	Leafroll	Recent	Individual	None
			Chronic	Average	None
			Individual	None	None
		Spindle tuber	Chronic	Average	None
		Giant hill	Chronic	Average	None
	1934-35 ⁴	Mild mosaic	Chronic	Average	None
		Rugose mosaic	Recent	Individual	None
			Chronic	Average	None
			Recent	Individual	None
			Chronic	Average	None
Copper discoloration	1933-34 1934-35	Leafroll	Chronic	Average	None
		Spindle tuber	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
		Rugose mosaic	Chronic	Average	None
			Chronic	Average	None
Water intake	1934-35	Leafroll	Chronic	Average	None
		Spindle tuber	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
Toluolized water	1934-35	Leafroll	Chronic	Average	None
		Spindle tuber	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
Phenosafranin	1934-35	Leafroll	Chronic	Average	None
		Spindle tuber	Chronic	Average	None
		Mild mosaic	Chronic	Average	None
Starch grains	1935-36	Leafroll	Chronic	Average	None
		Spindle tuber	Chronic	Average ²	Some
		Mild mosaic	Chronic	Average	None
		Rugose mosaic	Chronic	Average	None

⁴ Colorimetric tests.

Parts of the tuber. Skin toughness increased from stem (proximal) to bud (distal) end, while a decrease occurred with respect to flesh hardness and resistance to alternating current. The two ends were the same with respect to refractive index. Flesh hardness was less in the cortex than in the center, and was still less in between. These facts prove the necessity of standardizing tests even if they are as simple as these are.

Tuber weight. As tuber weight was less, there were these trends: less loss in weight absolutely but more in percentage; less of a percentage injured by cold; more of the severe type of freezing injury in one comparison, and less in another; more resistance to alternating current; less current generated; higher pH; and more water absorbed. Therefore tuber weight must be considered in any new kind of test. Tuber weight had no apparent correlation with skin toughness, flesh hardness, resistance to alternating

current, or refractive index. Of course, these conclusions may apply only to conditions described for these experiments.

Origins. The region in which the tubers were produced had an apparent effect on pH but none on resistance to alternating current. The portion of the field producing the crop influenced the effect of cold. Conditions of storage did not affect flesh hardness or freezing injury, but affected the refractive index.

Varieties. There was varietal difference in freezing injury, refractive index, and resistance to alternating current.

Other comparisons. Refractive index was highly correlated negatively with flesh hardness. With less resistance to alternating current, more direct current was generated by the tuber in one comparison out of three. There was no apparent relationship between skin toughness and periderm thickness; between flesh hardness and resistance to alternating current, generation of direct current, or pH; between freezing injury and refractive index or resistance to alternating current; between refractive index and resistance to alternating current, generation of direct current, or pH; between resistance to alternating current and generation of direct current (in two comparisons out of three) or pH; or between generation of direct current and pH. Evidently it is rare that one test can represent two or more.

LITERATURE CITED

1. Allen, F. W. Maturity standards for harvesting Bartlett pears for eastern shipment. Calif. Agr. Expt. Sta. Bull. 470, 27 pp., illus. 1929.
2. Bechhold, H., and F. Erbe. Zur biologie der kartoffel. XVI. Mitteilung. Studie ueber die Kolloidstruktur der Kartoffelknolle. Unterschiede zwischen Vital- und Abbauknollen. Arb. Biol. Reichsanst. Land- u. Forstw. Berlin 20:111-139. 1932.
3. Blake, M. A. A device for determining the texture of peach fruits for shipping and marketing. New Jersey Agr. Expt. Sta. Cir. 212, 8 pp., illus. 1929.
4. Craig, N. The use of the refractometer in cane seedling selection work. Internatl. Sugar Jour. 33:14-17. (From abst. in Expt. Sta. Rec. 65:36.) 1931.
5. Dixon, H. H., and W. R. G. Atkins. Osmotic pressures in plants. I.—Methods of extracting sap from plant organs. Sci. Proc. Roy. Dublin Soc. n. s. 13:422-440. 1911-1913.

6. Esmarch, F. Die Blattrollkrankheit der Kartoffel. Monograph. Pflanzenschutz hrsg. Morstatt 8, 91 pp., illus. Springer, Berlin. 1932.
7. Folsom, Donald, and Reiner Bonde. List of distinct potato viroses. Amer. Potato Jour. 13:14-16. 1936.
8. Folsom, Donald, F. V. Owen, and Hugh B. Smith. Comparisons of apparently healthy strains and tuber lines of potatoes. Me. Agr. Expt. Sta. Bull. 358, pp. 1-104. illus. 1931.
9. Gassner, G., and G. Goeze. Zur Frage der Frosthaertebestimmung durch refraktometrische Untersuchung von Pflanzenpressaeften. Phytopath. Zeitschrift 4:387-413. 1932.
10. Gortner, R. A., and W. F. Hoffman. Determination of moisture content of expressed plant tissue fluids. Botan. Gaz. 74:308-313. 1922.
11. Hartzell, F. Z. Application of one of Pearson's probability theorems and some special probability equations to entomological data. Jour. Econ. Entomol. 22:202-209. 1929.
12. Magness, J. R., and George F. Taylor. An improved type of pressure tester for the determination of fruit maturity. U. S. Dept. Agr. Dept. Circ. 350, 8 pp., illus. 1925.
13. McIntosh, T. P. Investigation on intervarietal differences of a chemical nature in the mature potato tuber. Scottish Jour. Agr. 40: 304-311. (From abst. in Amer. Pot. Jour. 5:372-373.) 1928.
14. McLean, W. The control of leaf-roll disease in potatoes by the diagnosis of "primarily infected" tubers. Jour. Agr. Sci. 16:149-157. 1926.
15. Ministry of Agriculture and Fisheries (Great Britain), Department of Agriculture for Scotland, and Ministry of Agriculture for Northern Ireland. Reports on the work of agricultural institutes and on certain other agricultural investigations in the United Kingdom 1931-1932. 1933.
16. Schultz, E. S., and Donald Folsom. Leafroll, net-necrosis, and spindling-sprout of the Irish potato. Jour. Agr. Res. 21:47-80. 1921.
17. Schultz, E. S., and Donald Folsom. Recent potato virus-disease information contributing to the production of better seed potatoes. Potato Assoc. Amer. Proc. 15th Ann. Meeting, New York, 1928, pp. 203-227. 1929.
18. Sherwood, Sidney F. Use of the refractometer in the analysis of individual sugar beets. Jour. Agr. Res. 36:41-52. 1928.
19. Sweetman, Marion D. Color of potato chips as influenced by storage temperatures of the tubers and other factors. Jour. Agr. Res. 41:479-489. 1930.
20. Wright, R. C., and H. C. Diehl. Freezing injury to potatoes. U. S. Dept. Agr. Tech. Bul. 27, 23 pp., illus. 1927.
21. Youden, W. J. Statistical analysis of seed germination data through the use of the chi-square test. Contrib. Boyce Thompson Inst. 4:219-232. 1932.

